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NASA PROJECT APOLLO WORKING PAPER NO. 1016

PRELIMINARY STUDY OF A PULSE CODE MODULATION DATA ACQUISITION AND REDUCTION SYSTEM FOR SUPPORT OF PROJECT APOLLO

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE TASK GROUP

Langley Field, Va.

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Prepared by: Robert E. Bobola
Robert E. Bobola
Aeronautical Research Engineer

Authorized for Distribution:

C J Donlan
for Robert R. Gilruth, Director

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1.0 SUMMARY

1.1 Pulse code modulation (PCM).- PCM is a means of providing a digital representation of a time-varying analog signal. Such a signal is sampled and then digitized by an analog-to-digital converter. The output is usually in the form of a standard IRIG serial non-return-to-zero (NRZ-information content indicated by change in level) signal which is applied to the input of an FM transmitter. Detection problems at the receiver are reduced to discriminating between the absence or presence of a pulse. A binary code is the most common, and its resolution depends upon the number of digits in each code group. One of the most prominent advantages of PCM is the complete regeneration of a signal which has been degraded in transmission through the communications link. This regeneration process extends far beyond that obtainable with other types of modulation.

The basic functions of a PCM data reduction system are signal detection and regeneration (reconstruction of incoming signal); synchronization (separation of individual channels, words and frames from the serial input to the synchronizer); decommutation (generation of control pulses to the digital-to-analog converter); and digital-to-analog conversion (reconstruction of analog waveform of individual channels).

Existing data reduction facilities involved in the Mercury program do not have PCM capability. Atlantic Missile Range (AMR) is in the process of adding a PCM capability. In general, it would not be feasible to modify equipment now in use due to the completely different format of PCM.

2.0 INTRODUCTION

The purpose of this paper is to present a preliminary study of a facility capable of supporting the data requirements of Project Apollo. The possibility of increased data loads, which consequently might demand faster methods of data reduction, indicates that modification of existing telemetry acquisition and reduction facilities should be considered.

In anticipation of this problem, a brief discussion of PCM, a general approach to a PCM data reduction facility and the possibility of modifying existing data reduction centers are presented in this paper.

3.0 GENERAL

To gain any efficiency of transmission, information must be processed in some way before being transmitted over an intervening medium. This process is called the "modulation process." Although there are many ways of producing modulated signals, they are broken down into two basic forms - continuous-wave modulation (C-W) and pulse modulation (PM). PM realizes more efficient utilization of transmission facilities.

3.1 Pulse Code Modulation (PCM).- PCM is the digital representation of a continuously varying analog signal sampled at discrete intervals. Since noise introduced during transmission of a signal makes it impossible for the demodulator circuit to detect all fine variations in signal amplitude, there is no need to transmit all signal amplitudes as is done in most methods of modulation (analog methods). The analog methods do not present a favorable exchange of bandwidth for signal-to-noise ratio. In PCM, information is transmitted by means of a code of a finite number of symbols representing a finite number of possible values of the information at the time of sampling. A binary code is one example of the coding possible in a PCM system and, because of the convenience of bistable circuits such as multivibrators, is usually used in pulse-code communications. This binary code can be transmitted as the presence or absence of a pulse in a sequence of N pulses. The chart in figure 1 compares a four-digit binary code to the decimal digital system. Here, the number of different combinations of values is 2^N where N is the number of digits in a code group in which each digit has two possible values. As was previously stated, a binary group is not the only one which may be used. In general, for X digits and Y possible values, the number of possible combinations is Y^X. Therefore, in PCM a group of digits is used to represent the value of the signal being sampled at discrete quantizing levels.

3.1.1 Sampling and digitizing.- Figure 2 is an example of a signal being exposed to the quantizing levels. The levels are separated "v" volts apart. The number of quantizing levels is equal to the total voltage differential divided by the voltage separating each level ($L = V/v$). From this development, it is immediately obvious that PCM introduces a new problem. Since the code can only transmit certain discrete values, the signal must sometimes be "quantized" to the nearest discrete value which can be transmitted by the code. The error or "noise" introduced by quantizing is called quantization error or quantization noise. The ramifications of this error could be studied in great detail, but it is enough to say that it can be minimized by decreasing the level separation "v"; i.e., increasing the number of levels "L" used. Figure 3 shows one process by which an analog signal is coded for PCM.

3.1.2 Coded system.- The final coded samples (fig. 3 (d)) are an example of a four-digit binary system. Therefore, each set of pulses has 2^4 or 16 possible values. The maximum possible error or quantization noise which could be introduced would be one level out of 16 or 6.25 percent. The resolution of the system is therefore 0.0625. This is not necessarily the accuracy of the telemetered signal. To determine the value of a series of pulses is quite simple. The presence or absence of the pulse is the only criterion. For example, in a four-digit binary system the method of evaluation is as follows: each pulse from right to left in each particular group represents the number 2 raised to the power that corresponds to the position of the pulse. The positions are "zero," "one," "two," and "three." The presence of a pulse in the "zero" position represents the number 2 raised to the zero power or 1 ($2^0 = 1$). A pulse in the "one" position represents the number 2 raised to the first power and so on up to 2^3 or 8. If a pulse is missing, it is not counted, but it should be realized that it does have significance in the sense that it represents the absence of a particular pulse in a particular position or zero.

3.1.3 Applications and advantages.- From the foregoing discussion, it can be realized that a receiver need only distinguish the presence or absence of a pulse to be capable of reconstructing the original waveform. This factor is extremely significant. It drastically reduces noise problems which reduce the efficiency of many other modulation processes. To conclude this brief discussion, it might be well to enumerate the applications and advantages of PCM:

(1) As long as the signal-to-noise ratio is above

threshold, PCM signal-to-noise ratio (S/N) is independent of carrier S/N; thus, the S/N of PCM is constant.

(2) PCM provides an exponential increase of S/N with bandwidth.

(3) PCM is ideal for relaying purposes because as long as the carrier signals are well above threshold, no noise is added by individual links in the relay chain. For this same reason, PCM is ideal if the code groups are stored as such or fed into digital computing equipment because no additional quantization noise is introduced.

(4) The necessity of a linear system can be waived since the circuitry need only distinguish absence or presence of a pulse. As a result, a large part of the system can be quite conservative in design since component and input tolerances are far from critical in many cases. This greatly increases system reliability.

(5) Data reduction time can be reduced.

(6) Complex systems can be constructed with simple components. This immediately points out the advantage of ease of manufacture and maintenance.

(7) A wide variety of tasks such as a logical operation (arithmetic) are quite adaptable through the use of digital computers and discrete servosystems.

The advantages and applications just enumerated may be summarized by saying that pulse-type systems offer extreme flexibility and excellent reliability. The advent of pulse-type circuitry has allowed the state of the art to develop to techniques which perform functions once impractical with conventional techniques.

4.0 PCM DATA REDUCTION FACILITY

Since this paper deals only with a PCM reduction facility, no effort shall be made to suggest or describe a PCM telemetry system except for a very brief introduction to the telemetered signal. There will be no discussion of any particular analog word structure, analog signal level, primary frame size, frame identification, word synchronization for telemetry, individual channel sampling rate, bit rate, digital input, or PCM output. A general reduction system which can handle a variety of parameters will be presented.

4.1 Incoming signal.- As was previously shown in figure 3, the transducer output is sampled, quantized, and digitized. The sampling rate must be high enough with respect to the maximum frequency signal in the sample input so that intolerable errors are not introduced in the sampled data pulse train. These errors are caused by "frequency folding" of the original frequencies about the sampling frequency, in the resultant sampled data frequency spectrum. The digitized output shall be referred to as the analog-to-digital converter (ADC) output. The filter for the ADC output commonly has a cutoff frequency of approximately $\frac{1}{2}$ the bit rate. Current figures show bit rates ranging from as low as 64 bits per second to as high as 500,000 bits per second. The output code is a standard IRIG serial NRZ signal. It is realized that this statement is open to discussion as to just what is meant by "standard NRZ signal." Actually, it might be better to say "modified" NRZ - a transition at each change of state. Pure NRZ has a transition at every "one" bit. This system is not used to any extent. The NRZ signal is applied to the input of an FM transmitter. PCM/PM and PCM/AM may also be used. Proper time sequencing of all multiplexing switches and d-c restoring switches is accomplished by a program unit. This unit also generates a frame synchronizing signal which, for example, could be a "word" (an ordered set of characters which is the normal unit in which information may be stored, transmitted, or operated upon) of all binary "one's." The ADC usually cannot generate any data which would make up a "sync word" except during the frame synchronization period.

Figure 4 is a simple block diagram of a one-channel PCM system.

4.2 System.- A flexible PCM data reduction facility should be capable of accepting the output of the airborne system either in real-time (directly from the receiver) or from a tape recorder during playback. The purpose of the following system breakdown is to present the functional operations of a PCM reduction system in a logical manner. There might well be disagreement as to the importance of the parameters discussed. Some portions of a PCM data reduction facility are merely mentioned in passing, whereas others are covered in some detail.

Figure 5 attempts to pick up loose ends by presenting a complete system in block diagram form.

4.2.1 Signal detection and regeneration.- The incoming PCM/FM signal from the receiver or tape playback unit must be detected and regenerated in some manner. If a tape playback unit is used, it is almost always necessary to incorporate some means of providing variable delays to correct for static skew in the tape record heads, and some type of summing network to correct for signal dropout. Pulse detection is commonly accomplished by a decision circuit, the purpose of which is to decide whether or not a pulse is present. The decision circuit usually has two inputs. One is from a bit rate detector and the other is from the receiver. The bit rate detector operates on transition pulses in the signal to phase-lock an oscillator with the incoming NRZ pulse train. It then serves two purposes. A clock-rate sine wave and a clock-pulse are generated for tape recording and logic circuits respectively. The decision circuit (commonly a slicing circuit with d-c restoration) makes use of this clock-pulse along with the incoming signal to reconstruct the incoming signal and then feed it to an accumulator. At this point, the accumulator output may be fed to a digital tape recorder with a format suitable for computer processing.

As the pulse train from the receiver is fed into the bit rate detector, it is differentiated and rectified. This output, which is a positive going pulse train where each pulse represents a transition in the input wave, is fed into a level detector which cancels out noise pulses of less amplitude than the signal. A phase discriminator then compares a phase-lock oscillator with this output so that the oscillator can be quickly locked to the same frequency as the input pulse train. The time constant of the phase discriminator is usually such that it will maintain synchronization during short signal dropouts.

The decision circuit accepts the incoming signal and compares it to the incoming waveform in a differential amplifier. This output is normally fed to a Schmitt trigger which makes a continuous decision. The trigger decides whether a "zero" or a "one" bit is present. The output is fed to a multivibrator (bistable circuit) which is triggered by the clock rate. The output of the multivibrator is the regenerated pulse train.

4.2.2 Synchronizer.- The synchronizer is the heart of a PCM system. In some cases the bit rate detector, accumulator, decommutator, and decision circuit are part of the synchronizer package. It is the master control unit of a PCM system. Besides providing control logic, the synchronizer is an accumulator providing a parallel data output to the digital-to-analog converter and some type of computer format translator.

The two phasing conditions necessary for proper synchronization are proper framing of each word and designation of each word with respect to the entire data frame. This dictates a need for word synchronization and frame synchronization. Frame synchronization is both a necessary and sufficient condition for data synchronization. Bit and frame rate are the only two types of synchronization necessary. Once determination of the major frame synchronization rate has been accomplished, the bit rate can be used to sequence and reset counters in the decommutator (see section 4.2.3) without using word synchronization. If by some chance there is only acquisition of the minor frame rate, certain channels of information will be rendered useless. If all channels are to be reduced, frame synchronization must be acquired.

The synchronizer searches for and locks on the synchronization codes present in the serial PCM data. The two major inputs to this unit are the reconstructed pulse train from the accumulator and the clock pulses from the bit rate detector. Its operation depends upon these two known inputs. The synchronizer must know the exact nature of the code and the rate at which it occurs. Noise within the communications channel can change the nature of the code even though the repetition rate does not vary. Consequently, there has to be some allowance for error in the synchronization code. Any synchronization pattern recognizer must, therefore, employ the autocorrelation properties of the incoming signal. Once synchronization has been achieved in the search mode (accomplished once properties of code configuration and repetition rate have been determined), some type of synchronization separator should go into the synchronization mode where it is locked on to the incoming synchronization code and will flywheel during short signal dropouts. After locking on, the synchronization separator controls the phasing of the counters in the decommutator. A synchronization separator can be divided into two parts - one part recognizes synchronization patterns and the other provides the necessary logic to distinguish between the search and synchronization modes of operation.

4.2.2.1 Synchronization pattern recognizer.- This circuit, used for major and minor frame synchronization detection, must be capable of correcting for synchronization pattern corruption by errors and premature "sync" indication.

4.2.2.2 Control logic.- This circuit insures that the output of the synchronization pattern recognizer is correct by correlating repeated recognition pulses with the known repetition rate. Control of the search and synchronization mode control logic is accomplished through the use of major and minor frame synchronization recognition pulses received from the synchronization pattern recognizer. Bit rates, furnished by the bit rate detector, are also involved in the control logic. The output is fed into the decommutator in the form of reset pulses.

4.2.3 Decommutator.- The complexity of the decommutator depends upon the form of information output desired. It can become especially complex, for example, if certain syllables or parts of a word, rather than the whole word, are desired. The decommutator discussion is far from a complete analysis and is merely intended to present a brief functional description of one type of decommutator.

The decommutator obtains its input from the synchronization separator. The two inputs are the bit rate and reset pulses. Rather than directly decommutating the analog data, the decommutator generates properly phased control pulses for the digital-to-analog converter at the digital level. The output of the decommutator is a number of control pulses. A patchboard should be available so that control pulses may be selectively programed to yield control pulses to the digital-to-analog converter. The decommutator usually consists of a bit counter, a syllable counter, and a frame counter. The bit counter (driven at the clock rate by the bit rate detector) supplies stepping pulses to the frame and syllable counters. Proper phasing in all three counters is provided by the major frame rate and word rate outputs from the synchronization separator. The syllable and frame counter outputs are the inputs to the decoding matrices. The output of these matrices should be control pulses to a patchboard. The syllables within a major frame recombine to represent the analog channels.

4.2.4 Digital-to-analog converter.- The digital-to-analog converter consists of a holding circuit and decoding network.

4.2.4.1 Holding circuit.- Although the holding circuit for a digital-to-analog converter could be either analog or digital, a digital system should be used since it offers greater accuracy. The inputs to this network are the decommutation control pulses and the information from a data bus.

4.2.4.2 Decoding network.- The output from this network is the desired analog signal.

4.3 Tape recorders and receivers.- Tape recorder and receiver blocks are definitely major parts of a data reduction facility intended to have real-time as well as tape playback capability. These items were not covered in any detail, however, since they are not peculiar to a PCM system. A digital tape recorder would be incorporated for recording tapes for computer processing. In this case, the signal would be taken from the output of the synchronizer and fed into a computer format control unit (computer language translator) which would finally feed the proper record signal to the tape unit.

4.4 General.- There are, of course, many other components involved in a PCM data reduction facility, such as PCM simulators (provide variable bit rates, amplitude outputs, programable binary codes, selectable "sync" codes, output clock pulses, channel sampling rates and formats), calibrators, etc., which do not necessarily merit discussion in a preliminary paper. One final point might be made. The system described is quite flexible in the sense that it offers real-time input, tape playback input, analog output and digital output. Many facilities would not require this much flexibility.

5.0 EXISTING FACILITIES

It would not be feasible to attempt to modify existing range reduction facilities for PCM capability due to the completely different format of PCM.

5.1 Receivers are the only major existing items that need not be modified. Even such a flexible thing as an analog tape recorder cannot be modified for digital work without almost completely replacing the tape transport. A few examples might be cited: An analog recorder has a relatively long start and stop time compared to a digital recorder. This time cannot be tolerated in a digital recorder which goes to elaborate means, such as buffer storage and vacuum storage, to insure that the tape has reached operating speed when an information record is presented to the heads. In analog recording, "wow and flutter" (instantaneous tape speed variation) is very important and "skew" (deviation of tape from normal path) is of lesser consideration. There is a complete reversal in the importance of these factors in digital recording. Digital recorders use careful tension control along with extra long tape guiding troughs to correct for possible tape skew. In general, analog recorders are out of phase in their requirements as compared to digital recorders.

5.2 Atlantic Missile Range (AMR) is in the process of orientating itself towards PCM capability. They have not, however, attempted to modify existing facilities. New equipment has been purchased. It was definitely concluded that modification of present equipment was not practical.

5.3 The incompatibility of existing facilities with PCM might suggest a compromise between the two – such as PACM (a combination of PAM and PCM). This paper will not attempt to carry a hybrid system discussion to any further extent. It is intended merely to make a few points:

(1) If any form of a PCM system is used, new equipment must be purchased.

(2) Since facilities already have PAM capability, use of the increased flexibility could be made.

(3) A hybrid system is a possible solution and definitely merits some consideration.

It is realized that use of a hybrid system would definitely be dictated by airborne requirements rather than ground.

6.0 PCM STATUS CHARTS

The three charts presented here are taken from "A Survey of PCM Progress" by R. L. Sink. Chart I is a listing of some identified PCM telemetry programs. Chart II lists the operating parameters of currently active PCM systems. Chart III tabulates experience concerning telemetry transmission of PCM from a moving vehicle to a receiving site. These charts are up to date as of May 1960.

CHART I
PROGRAMS OF PCM TELEMETRY EQUIPMENT

	ACTIVE USE					PENDING SERVICE[3]					OUT OF SERVICE			IN-DEVELOPMENT		
EQUIPMENT OWNER	Space Tech. Labs.	Holloman ADC	Douglas Aircraft (Santa Monica)	North American Aviation (Columbus)	Jet Propulsion Lab. Sperry (Utah)	Northwestern Univ.-Aerial Measurements Lab. (BuAer-Sponsor)	Republic Aviation N.A.T.C. Patuxent	Northrop (Hawthorne)	General Electric (Edwards)	Eglin AFB	WADC	North American Aviation (Los Angeles)	Martin Co. (Baltimore)	Boeing (Seattle)	A. C. Spark Plug (Milwaukee)	Jet Propulsion Lab. Sponsor
DESIGNATION	Tele-bit	Mark II	ADHS	Mars	(Sergeant Missile)		SPCM-896-15, 16		Project Advance		AN/AKT-14[4]	Daisy II	YP6M-1 System	(Minuteman Program)	(Titan Program)	Digilock
MANUFACTURER	Space Tech. Labs.	Radiation	Datalab Division of CEC	N.A.A. Columbus	C-G Electronics - Gulton Ind.	Datalab Division of CEC and Northwestern Univ.	Epsco	Radiation	Radiation	Epsco	Radiation[5]	N.A.A.	Martin (System Eng.) and three Subcontractors	N.A.A.-Autonetics and Radiation	Radiation	Space Electronics
NO. OF SYSTEMS	6	1	4	2	Approx. 30	1	3	1	3	1	No information	1	1	None delivered	None delivered	1 ordered. None delivered
NO. IN[1] ACTIVE USE	1[2]	1	3	1	Approx. 30	0	0	0	0	No information	No information	0	1[6]	0	0	0
NO. HRS. USED PER NO. TO GATHER DATA	720[2]	4	25 to 30	5	1 (Per System)	0	0	0	0	No information	No information	50 Flights 1957-1958	10	0	0	0

NOTES:

(1) Active use is defined to include only those equipments that are being used in a data gathering situation where the primary effort is not to prove operation of the PCM system. Spare systems or components are not listed as active.

(2) One successful flight in Explorer VI. Telemeter went silent in approximately 1500 hours.

(3) Additional programs are believed to exist but information was either obscure or could not be obtained.

(4) AN/AKT-14 Systems have also been delivered to Convair-Astronautics, and Emerson Electric.

(5) Radiation, Inc., did not have antenna transmission or reception responsibility on AKT-14.

(6) Installed in flight test aircraft from January through July 1959, during which time system de-bugged and used to acquire data to complete test program. Termination of Seamaster contract interrupted further use of system.

CHART II

OPERATING PARAMETERS OF PCM SYSTEMS

EQUIPMENT OWNER	Space Tech. Labs.	Holloman ADC	Douglas Aircraft (Santa Monica)	North American Aviation (Columbus)	Northwestern Univ. (Aerial Measurements Lab.)	Jet Propulsion Lab. Sperry (Utah)	Republic Aviation N.A.T.C. Patuxent	General Electric (Edwards)	Eglin AFB	Boeing (Seattle)	A. C. Spark Plug (Milwaukee)	Jet Propulsion Lab. Sponsor	Martin Co. (Baltimore)
WORD STRUCTURE (No. of Bits)	12 Max. 10 Digital or 6 Analog + 4 Other	10	10 + Sign for Data 1 Parity 1 Event	9 + Sign	9 + Sign for Data 1 Parity. 1 Random Events	12 Data (BCD) 4 Parity 6 Word Ident. 8 Other	9 + Sign 3 Event 1 Parity 13 Digital	11 for Data 1 Parity	9 + Sign 3 Event 13 Digital	8 Data mixed with Computer Data Total of 27	27 of 8 Analog, 8 Digital, 8 Analog + 3 Word Sync	16 Total 5 Data + 11 Redundant	11 Data 1 Parity 1 Word Sync 1 Timing and Frame Sync
FRAME LENGTH (Words)	11	32	20 to 110	180	20 to 50 + "Inserted" Words at Event Periods	12	10 Analog + 15 Digital	90 Analog + 10 of Special Marking	25 Analog + 2 Digital + 2 Time	30 Millisecond Intervals		30	1000
SYSTEM SPEED (In Bits per Sec.)	1,8, or 64 at 6 Samples/Sec. Max.	264,000 at 24,000 Samples/Sec.	455,000 Max. at 35,000 Samples/Sec.	100,000 10,000 Samples/Sec.	385,000 Max. 1,280 to 32,000 Samples/Sec.	3,360 120 Samples/Sec.	350,000 Max. 25,000 Samples/Sec.	280,000 Max. 20,000 to 2,500 Samples/Sec.	325,000 25,000 Samples/Sec.	345,600 25,600 Samples/Sec. Analog Data, 12,800 Samples/Sec. Digital Data	172,800 ± 10%	409,600 25,600 Samples/Sec. Max.	14,000
SIGNAL SOURCES (No. of Channels and Signal Levels)	16 (Sub-com) 0-3V F.S. 3 (Prime) 0-3V F.S. 6 Digital Inputs	32 at 10.23V F.S. or 7 MV F.S. at Amplifier or 32 Digital Inputs	100 Prime ± 10 MV F.S. Each Prime Channel may be Sub-com to 10 or 100 Channels ± 10MV F.S. Total max. capacity 10,000 Channels. 20 11-Bit Digital Inputs	180 at ± 25 MV F.S.	50 at ± 5V F.S. and up to 16 10-Bit Digital Inputs. Special Events may expand frame size	12 at ± 5V F.S.	32 at 5V 13 at 5MV 25 at 5V 20 at 25MV 15 13-Bit Digital Inputs	± 5V F.S. or ± 10MV F.S. in Groups of 15	5 ±50 MV 23 ± 500V	328 Max. at 5V F.S., or 164 at 20MV F.S., or combination of High and Low Level	64 at 5.10 Volts F.S. + 5 8-Bit Digital Inputs + Computer Input	30 Analog 0-5V F.S. 10-Bit Digital Inputs	400 at ± 1V F.S. 600 at ± 30MV F.S. (Any combination totaling 1000 Channels permissible)
RESOLUTION	1/64	1/1023	1/2045	1/1023	1/1023	1/1000	1/1023	1/2016	1/1023	1/256	1/256	1/32	1/1000
ACCURACY	2%	0.4%	1 Bit at 5V 0.2% at 10 MV	1%	± 1 Bit	0.2%	± 0.1% for 5V; ± 1.0% for 25MV	± 0.2% of F.S.	± 0.2%	Not known	1%	3%	0.3% for 1 V 1.0% for 30MV
SYNCHRONIZING A. Frame	Unique Code All "0"	AM Modulation superimposed on FM Modulation	Unique Word All "1's"	Separate Track on Tape	Unique Word All "1's"	None. (Each word has distinct identification)	Unique Word	Unique Word All "1's"	Unique Word All "1's"	3-Bit Combined Word and Frame	Classified	Unique Word	Separate Track on Tape
B. Word	0-1 Transition Between Words	Uses Frame Sync	0-1 Transition Between Words	Recorded Only	Recorded Only	(1)	0-1 Transition Between Words	Recorded Only	0-1 Transition Between Words		3 Bits	Must have prior system synchronization during preparatory transmission but can maintain sync with fading	Recorded Only

(1) Each word is a 4 by 7 bit serial-parallel combination. Six bits of the first 7-bit "character" of each word is used to identify the word.

CHART III
TELEMETRY TRANSMISSION OF PCM
(EXISTING SYSTEMS)

EQUIPMENT OWNER	Space Tech. Laboratories	Douglas Aircraft (Santa Monica)	Holloman ADC	N.A.T.C. Patuxent	Jet Propulsion Laboratory Sperry, Utah
TRANSMISSION					(2)
FREQUENCY	378 MC	1450 MC	800 MC	1435 - 1535 MC	258.5 MC
SPECTRUM USAGE		3 X Bit Rate	2 MC	2 MC	-
POWER	5 Watts	40 Watts	10 Watts	20 Watts	2 Watts
TRANS. ANT. GAIN	0 DB	0 DB	1 DB	4 DB	0 DB
BIT RATE	1, 8, or 64/Sec.	Up to 525,000/Sec.	264,000/Sec.	512,000 Max./Sec.	(3)
MODULATION	PCM-FM-PM (Bi-Phase Sub-Carrier)	PCM-FM	PCM-FM + AM Sync.	PCM-FM	PCM-FM-FM
RECEIVER	(1)				
ANT. GAIN		27 DB	10 DB	10 DB	8 DB
I.F. BANDWIDTH		2 MC	3 MC	6 MC	0.3 MC
NOISE FIGURE		8 DB	6 DB	8 DB	100 DBM
SYSTEM DESIGN LOSS		162 DB			
DESIGN DROP-OUT RATE	1×10^{-2}	1×10^{-6}	1×10^{-5}	Not specified	1×10^{-4}
EXPERIENCE				None to date	
DESIGN RANGE	500,000 Miles at 64 Bits/Sec.	100 Miles at 5000 ft. Alt.	3.5 Miles at Gnd. Level		Not stated
ACTUAL RANGE		125 Miles at 6000 ft. Alt.	3.5 Miles		80 Miles
FADE EXPERIENCE	Not reported	Altitude-sensitive. Some evidence of multi-path fading due to reflection from near-by buildings.	Problems from multi-path fading from metal post at track, rails of track. Primary transmission problem attributed to AM sync pulse method.		Data not extensive enough to draw positive conclusion.

(1) Various receiving sites at Hawaii, Cape Canaveral, Manchester, etc.

(2) Parallel output to seven FM sub-carrier oscillators.

(3) RF link multiplexed with other information besides PCM.